PERFORMANCE OF ASPHALT MIXTURES CONTAINING STEEL SLAG AGGREGATE AND SYNTHETIC FIBERS

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To my beloved parents, wife and sons, Dr. Moha mmed Hezam Alnadish, Mrs. Hosen Alnadish, Mrs. Hadeel Alnadish, Broourg and Mohammed

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ABSTRACT

Utilization of waste materials in civil engineering applications has been documented as an effective method to preserve environment and natural resources. One of the well-known waste materials is steel slag aggregate, which is a by-product of steel manufacturing. However, volume instability and high density are the main drawbacks of using steel slag aggregates. In this study, steel slag aggregates were immersed in water for six months to minimize the free lime and free magnesia content, which are mainly responsible for the volume instability. Furthermore, the granite aggregates were replaced by electric arc furnace (EAF) steel slag aggregate with different proportions to identify the suitable substitution in terms of superior performance. Subsequently, the asphalt mixtures incorporated the appropriate proportion of the steel slag aggregates were reinforced with polyvinyl alcohol (PVA), acrylic, and polyester fibers at different dosages of 0.05, 0.15, and 0.3% by weight of the aggregates, respectively. The conducted performance tests were resilient modulus, dynamic creep, rutting depth, moisture susceptibility, and cracking resistance. The findings of this study showed that the free lime and free magnesia content in the treated steel slag aggregate have significantly decreased. On the other hand, the asphalt mixtures incorporated coarse steel slag aggregate exhibited the best performance than the other substitutions. Furthermore, introducing synthetic fibers have dramatically enhanced the cracking resistance. The higher the fiber content, the higher the resistance to cracking. Additionally, the outputs of the permanent deformation tests showed that as the fibers dosages increase, the deformation increases due to the densification. Moreover, the asphalt mixtures performance incorporating 0.15% of synthetic fibers possesses the ability to decrease the thickness of the asphalt layer by about 10%. In conclusion, improving the performance of asphalt mixtures through utilization of steel slag aggregate and synthetic fibers is a successful approach in terms of extending the service life of asphalt layer.

ABSTRAK

Penggunaan bahan sisa yang diaplikasikan dalam bidang kejuruteraan awam telah direkodkan sebagai satu kaedah yang berkesan untuk memelihara alam sekitar dan sumber semula jadi. Salah satu daripada bahan sisa yang terkenal adalah agregat sanga keluli, yang merupakan hasil sampingan pembuatan keluli. Walau bagaimanapun, ketidakstabilan isi padu dan ketumpatan tinggi adalah kelemahan utama yang dikenalpasti dalam penggunaan agregat sanga keluli. Dalam kajian ini, agregat sanga keluli telah direndam di dalam air selama enam bulan untuk mengurangkan jumlah kapur bebas dan kandungan magnesia bebas, yang terutamanya bertanggungjawab terhadap ketidakstabilan isi padu. Tambahan pula, agregat granit telah digantikan oleh agregat sanga keluli daripada relau arka elektrik (EAF) dengan perkadaran yang berlainan untuk mengenal pasti penggantian yang sesuai dari segi pencapaian prestasi. Selepas itu, jumlah campuran asfalt yang sesuai telah dimasukkan Bersama agregat sanga keluli yang diperkuat dengan polivinil alkohol (PVA), akrilik, dan serat poliester pada dos yang berbeza iaitu 0.05, 0.15, dan 0.3% daripada berat agregat. Ujian prestasi yang dijalankan adalah modulus berdaya tahan, rayapan dinamik, kedalaman rut, kerentanan kelembapan, dan rintangan retak. Penemuan kajian ini menunjukkan bahawa kandungan magnesia dan kapur bebas dalam agregat sanga keluli yang dirawat telah berkurangan. Sebaliknya, campuran asfalt yang dipadankan dengan agregat terak keluli kasar menunjukkan prestasi yang terbaik. Selain itu, pengenalan serat sintetik telah menunjukkan peningkatan yang ketara ke atas rintangan retak. Semakin tinggi kandungan serat, semakin tinggi rintangan untuk retak. Di samping itu, hasil ujian ubah bentuk kekal menunjukkan bahawa apabila dos serat bertambah, perubahan bentuk akan meningkat disebabkan oleh densifikasi. Selain itu, prestasi campuran asfalt yang menggabungkan 0.15% gentian sintetik mempunyai keupayaan untuk mengurangkan ketebalan lapisan asfalt sebanyak kira-kira 10%. Kesimpulannya, meningkatkan prestasi campuran asfalt melalui penggunaan agregat sanga keluli dan serat sintetik adalah satu pendekatan yang berjaya dari segi melanjutkan hayat perkhidmatan lapisan asfalt.

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LIST OF SYMBOLS AND ABBREVIATIONS

AASHTO	-	American Association of State Highway and Transportation Officials
ASTM	-	American Society for Testing Materials
AV	-	Air voids
BOF	-	Basic oxygen furnace
BS	-	British standard
CR	-	Creep rate
DP	-	Dust proportion
DS	-	Dynamic stability
DSM		Dynamic stability modulus
EAF	-	Electric arc furnace
ESALs	-	Equivalent single axle load
G_{mb}	-	Bulk specific gravity of the compacted paving mixture
G_{mm}	-	Maximum specific gravity of the loose paving mixture
G_{sb}	-	Bulk specific gravity of the combined aggregate
G_{se}	-	Effective specific gravity of the aggregate
HMA	-	Hot mix asphalt
MEPD	-	Mechanistic Empirical Pavement Design
N_{des}	-	Number of revolutions to achieve 4% of air voids
N_{ini}	-	Number of revolutions to simulate the initial placing in filed
N_{max}	-	Number of revolutions that simulate the final air voids after densification by traffic load
NCHRP	-	National Cooperative Highway Research Program
OBC	-	Optimum bitumen content
P_{ba}	-	Asphalt absorption by the aggregate
P_{ba}	-	Effective asphalt content

PVA	-	Polyvinyl alcohol
RD	-	Slope rate of deformation
RM	-	Resilient modulus
RSM	-	Response surface methodology
SGC	-	Superpave gyratory compactor
SSA	-	Steel slag aggregate
SSD	-	Saturated surface dry
UTHM	-	Universiti Tun Hussein Onn Malaysia
VFA	-	voids filled with asphalt in the compacted mixture
VMA	-	voids in mineral aggregate in the compacted mixture
WMA	-	Warm mix asphalt
f-CaO	-	Free lime
f-MgO	-	Free magnesia
CaO	-	Calcium oxide
MgO	-	Magnesium oxide
Fe_2O_3	-	Ferric oxide
SiO_2	-	Silicon dioxide
Al_2O_3	-	Aluminium oxide
MnO	-	Manganese oxide
TiO_2	-	Titanium dioxide
Cr_2O_3	-	Chromium(III) oxide
°C	-	Celsius
mm	-	Millimetre
cm	-	Centimetre
m	-	Meter
µ	-	Micro
µs	-	Micro strain
µm	-	Micro meter
ε	-	Strain
kPa	-	Kilopascal
Mpa	-	Mega Pascal
N	-	Newton
kn	-	Kilo newton

mg	-	Milligram
g	-	Gram
kg	-	Kilo gram
min	-	Minute
s	-	Second
ms	-	Millisecond
R^2	-	R squared = coefficient of relationship
σ	-	Stress
ν	-	Position ratio
RPM	-	Revolution/minute
Hz	-	Hertz
P	-	Pressure
Pa.s	-	Pascal. Second

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Sustainable practices become a major focus concerning utilizing the waste materials due to the extensive use of natural resources in the construction and pavement projects. In addition, increasing costs of the raw materials for civil engineering applications prompted engineers and researchers to look for the industrial wastes as alternative resources. One of the well-known waste materials is steel slag, which is a by-product from the industrial steel manufacturing process, either by melting of iron in the basic oxygen furnace (BOF) or through melting of scrap in the electric arc furnace (EAF). Steel slag aggregates have been used in the asphalt mixtures for many decades, as long as the performance of the mixtures incorporated steel slag comparable or better than the mixtures containing natural aggregates (limestone, granite, etc.) concerning of the resistance of the mixtures to permanent deformation, cracking resistance, and stripping damage. In addition, steel slag aggregates are characterized by its porosity, angularity, hardness, and rough-textured, which makes the steel slag aggregates superior to the other waste materials in the asphalt mixtures. According to the researchers Ahmedzade & Sengoz (2009) and Kehagia, (2009) the mechanical properties of the steel slag aggregates offer asphalt mixtures with superior performance regarding the permanent deformation resistance and cracking resistance, this is because of the angularity and hardness of the steel slag aggregate that provides a stellar interlocking. The hardness of the steel slag aggregates is attributed to the iron content. Furthermore, the utilization of

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